DRYLAND AND IRRIGATED HARD RED WINTER WHEAT (*TRITICUM AESTIVUM* L.) MANAGEMENT IN THE CENTRAL GREAT PLAINS

by

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INTRODUCTION

Grain production in the central Great Plains is strongly influenced by extreme year to year variability in climate. Annual precipitation can vary from less than one-half to more than double the 425 mm average annual precipitation for the region (17). Although mean annual temperature is about 10^{o}C, daily summer temperatures can fluctuate by as much as 22^{o}C (16 to 38^{o} C). Given the extreme climatic variations, winter wheat is well adapted to this environment because wheat generally matures prior to the dry, hot part of the summer (7, 17).

Environmental conditions influence final grain yield by primarily affecting plant density (spikes /m^2) and grain weight (7, 23). Drought during reduction / division in pollen mother cells significantly reduces grain-set by reducing male fertility (32). Too little or too much water in the soil can reduce tiller production. However, drought stress during grain-fill (GS 10.5-11.1) also strongly affects grain yield. Drought may reduce the number of endosperm cells and small starch granules, which reduces the grain storage capacity (16). When these two factors are combined, the reduction in yield is greater than the effect of the individual components (16). Yield reduction is more severe when the stress occurs during the late period of endosperm cell division than during the early period (16).

Very low or high temperatures during grainfill have a negative effect on kernel weight and size (19). Short periods (24 h) of relatively high temperature exposure (>= 30^{o}C) during pollen mother cell meiosis results in male and female sterility similar to that caused by water deficit (24). Temperatures above the optimum range 18/13^{o}C to 21/16^{o}C day/night temperatures appear not to affect maximum cell number in the grain, but may reduce cell size and starch granule number (16). Yield reduction caused by drought is greater than that caused by high temperatures (16).

High winds can also influence on wheat yields in the central Great Plains. Windbreaks, strip cropping, and surface residue are common practices used to prevent wind damage to crops. Leaf damage caused by blowing soil increases diseases and reduces photosynthesis. Winds may also cause yield losses through increased lodging, which reduces crop harvesting efficiency.

Nitrogen is the most frequently lacking nutrient for optimum wheat production in Kansas (7). The amount of fertilizer and seed used is a function of the location, because rainfall ranges from 406 mm in the west up to 1016 mm in the east of the state. Average N rates for dryland and irrigated wheat in Kansas are 45 and 110 kg N /ha, respectively (9). In 1985, 81 % of all wheat acreage received N fertilizer and 43 % had P fertilization. The average rates were 64 and 37 kg/ha, respectively for N and P (30).

Research results suggest that grain yields are optimized with starter N applied at planting at rates up to 30 kg N / ha, with the balance applied in two or three spring splits at GS 3, 5, and if a third one is to be applied, in general should not be later than GS 8 by Feeke's scale (1, 6, 7, 16, 17, 29). However, several approaches for applying the remaining N in the spring are suggested by different authors. For some, the N rate for the spring split applications should be a function of available soil moisture and plant population. In the central Great Plains, if spring N is not applied up to or immediatly after joint stage yield will not be affected but normally increases grain protein (7, 29). For some Wisconsin researchers, the first split N rate is a function of plant population (19). With >18 plants/30 cm row lenght, 28 kg N /ha should be applied; if below that density, 56 kg N /ha is recommended. For the second split, 56 to 84 kg N /ha should be applied (19). Other authors (Kansas) prefer to apply 56 kg N /ha in the first two splits and 28 kg N /ha in the third split (22). The starter fertilizer will provide available N during the seedling growth period to insure an adequate stand and produce sufficient growth to improve overwinter survival (19). The first spring split N application, applied during tillering (GS 3), will help insure maximum tiller development, while the second split, at GS 5, will increase tiller survival and head formation (22). The third split, at GS 10, will delay senescence and increase grain protein content (22). The advantages of split N applications are 1) decreased N losses from leaching, 2) optimum available N at the most critical crop growth stages, 3) decreased lodging potential, and 4) increased flexibility for adjusting N rate to crop need.

In Kansas, 22 % of soils test low in available P (31). As with N, P deficiency or stress in wheat reduces tillering and increases the potential for winter - kill (19). Winter wheat is a cool season crop adapted to low soil temperatures and, thus, response to P fertilization is more likely to occur than in summer grown crops. This is primarily due to the slower rate at which organic and inorganic forms of P are released from the soil for plant use (29). On soils testing 'low' in plant available P or soils with a high P fixation capacity, P fertilizer efficiency is increased when the P is banded near or with the seed (12, 14, 19). Research in Kansas has shown that winter wheat response to N and P applied together in the same soil zone is greater than when applied separately (2, 3, 5, 6, 11, 18, 29). Phosphorus uptake is generally increased in the presence of NH_4-N, regardless of source (14, 18).

Seeding rate and row spacing can also influence grain yield by affecting plant density (19, 20, 27). Usual seeding rates in Kansas are about 45 to 56 kg/ha and 67 to 78 kg/ha for dryland and irrigated wheat, respectively. In general, increasing seeding rate will decrease the number of tillers/plant, kernels/head, kernel weight, and harvest index, but the number of plants/unit area and the number of heads/unit area will increase (19). Because most of the productive heads come from the main stem and first-order tillers, when using low tillering varieties, higher seeding rates increase the number of heads per unit area and final grain yield (22). However, some compensation in yield may be expected by increased number of kernels / head and kernel weight (4, 22). At very high N and seeding rates, decreased straw strength, increased lodging, and higher incidence of diseases have been reported (4, 27). The effect of seeding rate on increasing yield is also a function of the row spacing (4, 20, 27). For the same population, narrow rows increase the distance between plants in the row, which should increase light interception, photosynthesis, and tillering. Due to increased tillering, straw yields will generally increase (4, 19, 20). Several experiments in

Europe have shown 670 kg/ha yield increases by narrowing row spacing from 27 to 9 cm (20) .

Some plant growth regulators (PGR) are used to prevent or reduce lodging, because they reduce plant hight and increase straw strength (20, 27). Ethephon [(2-chloroethyl) phosphonic acid] (CERONE) has been shown to be more effective than chlormequat chloride on American wheat cultivars, while the opposite appears to be true for European cultivars (21). Ethephon generally does not enhance yields, although some results have shown yield responses (1, 21, 22, 32). Ethephon use is suggested mainly for cultivars that are likely to lodge, especially where high N and seeding rates are used, mainly under irrigation or where rainfall is high (21, 27).

The expression " intensive management " generally implies the use of high fertilizer rates (mainly N), high seeding rates, split N applications, application of antilodging agents, and good weed and disease control. Several European countries have reported yields above 4.7 MT/ha (19, 20, 27). Intensive management practices have been tried in several states in the United States with some yields above 6.7 MT/ha under irrigation (19, 20). Average yields for dryland and irrigated wheat in the central Great Plains are about 2.5 and 3.7 MT/ha, respectively. In Kansas, dryland wheat yields have increased an average of 33 kg / ha / year over the last 20 years. In general, improved tillage and weed control practices have contributed the most to yield increases (11). Although intensive management practices in humid regions have increased wheat yields, few studies have been conducted in the central Great Plains environment. The purpose of these experiments was to evaluate different management levels on dryland and irrigated hard red winter wheat yield production in the Central Great Plains region.

MATERIALS and METHODS

The dryland and irrigated wheat experiments were conducted between 1985 and 1987 at several locations in both Colorado and Kansas. The Colby dryland studies were located 16 km south of Colby, KS, while the Colby irrigated plots were located on the Northwest Research and Extension Center at Colby. Both soils were Keith silt loams (fine-silty, mixed, mesic Aridic Argiustoll). The Akron dryland study was located three km east of the Central Great Plains Research Station on a Rago loam (fine, montmorillonitic, mesic, Pachic Argiustoll). The Akron irrigated site was located 38 km south of Akron, on a Haxton silt loam (fine- loamy, mixed, mesic, Pachic Argiustoll). Conventional summerfallow tillage was used for weed control at the Colby dryland location, whereas chemical fallow weed control was used at the Akron dryland site. Soybeans [Glycine max (L.) Merr.] and wheat were the previous crops at the Akron and Colby irrigated sites, respectively. Soil samples were taken before sowing with a probe. For N, they were taken up to 1.5 m depth, with 30 cm increments. For P analysis, the sample was collected from 0 to 30 cm depth. All residues were incorporated by discing prior to planting. Selected soil properties for these locations are given in Table 1. The profile NO3-N contents are given as total NO3-N to 1.5 m, although over 50% of this N was concentrated in the surface 60 cm.

The management factors studied were seeding rate, N and P rates, N application timing, and plant growth regulation. The treatments used for both dryland and irrigated locations are listed in Table 2. Similar treatments were used for both dryland and irrigated studies, except that fertilizer and seeding rates were greater for the irrigated sites compared to the dryland sites (Table 2). The experimental design was a randomized complete block with four replications, and plots were 1.8 m by 7.7 m. Phosphorus rates were 12.2 (P1) and 24.4 (P2) kg P /ha for the dryland experiments and 24.4 (P1) and 48.9 (P2) for the irrigated sites (Table 2). Phosphorus was applied 5 cm below the seed at planting as ammonium polyphosphate (10-14.8-0). For the fall and spring N treatments, 17 and 34 kg N / ha were applied with the P2 rate in the dryland and irrigated studies, respectively. Where the P1 rate was used, the additional N to equal the N applied with the P2 rate was broadcast applied as NH_4NO_3 at planting . For the fall N treatments, the remaining N was also broadcast applied as NH_4NO_3. Nitrogen rates were 56 (N1), 112 (N2) and 168 (N3)kg /ha for the dryland sites and 112 (N1), 224 (N2), and 336 (N3) kg / ha for the irrigated experiments (Table 2). Seeding rates were 13.1 (S1), 20.5 (S2), and 27.8 (S3) * 10^5 seeds /ha for the dryland sites and 22.2 (S1), 33.4 (S2) and 44.5 (S3) * 10^5 seeds/ha for the irrigated experiments (Table 2). The spring split N applications were applied at growth stages 6, 8, and 10 (Feeke's scale). For the fall/spring treatments, 50 % of the N was applied in fall at planting and 50 % applied in the spring at growth stage 6.

Ethephon was applied immediately before the boot stage to selected treatments at a rate of 560 g ai /ha using a hand sprayer.

The cultivar Newton was planted at Colby in 1986/87 and 'Tam 105'was planted at Colby and Akron in 1985/86. All dryland locations and the Colby irrigated site were planted with 30 cm rows, while the Akron irrigated site was seeded on 18 cm rows. All the plots were sown using a 6-row International hoe drill modified to apply the fertilizer below the seed at planting.

At Colby irrigated site, 150 mm of water were applied on 20 May by gated pipe, while at Akron 130 mm of water was applied on 15 May with a center pivot. Planting and harvesting dates were: Colby dryland 85-86: 23 September 85 and 24 July 86; Colby dryland and irrigated: 27 September 86 and 3 July 87; Akron dryland: 7 October 85 and 7 August 86; Akron irrigated: 7 October 85 and 8 July

At physiological maturity, one m of row was hand-harvested from each plot by cutting plants 4 to 5 cm above the ground. After drying at 70^{o} C for 48 h the samples were ground in a Wiley mill to pass a 2-mm screen. Nitrogen and P content were determined after digestion with sulfuric acid / hydrogen peroxide (15).

At Colby, the two middle rows from each plot were harvested using a binder and a stationary thresher, while at Akron a small plot combine was used to harvest the four middle rows. After weighing, grain moisture and test weight were determined. Grain yields were corrected to 125 g /kg moisture concentration. From each plot, a subsample was ground using a 1-mm screen and analyzed for N and P. The digestion method was the same used for tissue analysis. Protein concentration in the grain was calculated by multiplying grain N concentration by 5.7. Nitrogen and P uptake in the grain were calculated. Analysis of variance and linear contrasts were calculated using 'SAS' computer program (25).

RESULTS

Colby Dryland 1985-1986

Averaged over all treatments, grain yield was 2.6 MT/ha, which is similar to average dryland wheat reported for this region (Table 3). Although annual precipitation (Table 4) was nearly normal (357 mm compared to 342 mm long term average), dry conditions persisted during the tiller and joint stages of growth. Thirty - seven percent of the total precipitation was received in May or just prior to grain fill, which helped offset the early drought effects. Air temperatures (Table 5) during grain filling were normal (15^{o}C in May and 22^{o}C in June) and no damaging winds or storms occurred. Averaged over all treatments, means of all the measured parameters except grain and tissue P were significantly increased compared to the check mean (Table 3).

The first N increment significantly increased yield, protein, N in the tissue, and N and P uptake. Increasing N rate up to 168 kg N /ha (N3), when averaged over P rates, significantly increased protein but had no effect on the other parameters. No significant differences were observed between fall and spring applied N . The high N and P content in the soil profile (Table 1), as well as the dryer-than-average period from tiller to joint stages, may explain the lack of response to N. Increasing P rates from 12.2 to 24.4 kg P /ha, averaged over N rates, significantly increased grain protein content, maybe due to greater N assimilation when greater amounts of P were present. The lack of response to P treatments observed in the other measured parameters is a result of the high P content in the soil (Table 1). There was not a significant N x P interaction.

Seeding rate strongly influenced all the measured parameters. Increasing SR increased yield, N in the tissue, N and P uptake, and decreased P in the grain. There was a significant SR x N interaction for protein. Grain protein concentration was similar with both S1 and S2 rates but significantly greater with the S3 rate. The decrease in protein with increasing SR is due to the dilution effect, because yield was increased. For P in the tissue, both S1 and S2 were significantly greater than S3. The SR effect was probably due to an increase in the number of productive heads. The same explanation is applicable to P in the grain and P and N uptake.

Akron Dryland 1985-1986

Rainfall from September 1985 through June 1986 was 302 mm, which is 25 mm above long term average (Table

302 mm, which is 25 mm above long term average (Table 4). Soil moisture at planting was excellent. Precipitation during fall tillering and the overwinter period was also above normal. Although rainfall during April and May was slightly above average, rainfall in June was only 33 mm, or 30 mm less than average. Therefore, some stress may have occurred in June during grain filling. Normal temperatures were recorded throughout the growing period (Table 6). No weed infestation, lodging, diseases, or damaging weather occurred.

Averaged over all treatments, grain yield was 2.6 MT/ha, which is slightly above average dryland wheat yield in this region (Table 7). All the measured parameters except P content in the grain were significantly increased in all treatments compared to the check (N0P0 S2).

When averaged over P rates, increasing N rate to 112 kg/ha (N2) significantly increased yield, grain protein, and N and P uptake in the grain. Compared to N2, increasing N rate to 168 kg N / ha (N3) had no effect on any measured parameter except grain protein and N uptake in the grain. Protein was increased about 1 % with each 56 kg N /ha increment. The moderately low soil profile N content (Table 1) and adequate moisture conditions strongly influenced the positive response to N fertilization.

Fall applied N1, when compared to spring split applied N1, significantly increased grain protein and P content. Grain protein was decreased by spring split N because the last N increment was applied at GS 10.52 after which little or no rainfall was received to move the last split into the root zone. The additional available N with fall application apparently enhanced P absorption by the crop.

Increasing P rate from 12.2 to 24.4 kg P /ha significantly increased protein (Table 7), which is probably related to enhancement of N or P assimilation when the other element is available. There was no significant N x P interaction.

Seeding rate, when averaged over N2 and N3, significantly affected yield and N and P uptake (Table 7). For the three rates, S1 was significantly lower than S2 and S3, while S2 and S3 produced similar results. Apparently, increases in SR increased the number of productive heads, but only up to the S2 rate, after which no significant increases were obtained. It is important to notice that grain protein remained constant (i. e., no dilution effect) with increasing yields obtained with increasing seeding rate. No significant N x SR interaction was detected.

PGR application did not significantly affect yields

Colby Dryland 1986-1987

Averaged over all treatments, yields were 4.2 MT/ha, which is about 2 MT/ha above average for dryland wheat in this region (Table 8). Air temperatures were about normal, while rainfall during the growing season was about 50 mm above normal for this location (Tables 5, 4). From September 1986 through June 1987, the total rainfall was 439 mm compared to 342 mm long term average for the same period. The favorable climatic conditions during tillering, jointing, and grain filling contributed to higher productivity at this site. Comparing check vs all other treatments, increasing inputs significantly increased all the measured parameters except N and P in the tissue and P uptake in the grain (Table 8).

The first N increment (56 kg N /ha) when averaged over P1 and P2 rates significantly increased yield and N and P uptake. Although not significant, grain protein (p=.15), tissue N (p=.16) and grain P (p=.14) were increased by adding 56 kg N / ha. Increasing N rate from 56 (N1) to 112 (N2) kg N / ha had no effect on yield, significantly increased N in the tissue, and only slightly increased grain protein (p = .14) and grain P (p =.18) Increasing N rate from 112 to 168 kg N /ha significantly decreased yield and N uptake but protein was significantly increased. Compared to 56 kg N / ha (N1), application of 168 kg N /ha significantly increased protein and N in the tissue. The negative effect on yield and N content at N3 is related to the low yield produced with the N3P2 S2 treatment. No explanation is forwarded for this low yield compared to either N2P2 S2 or N3P2F S2, where all the N was fall applied. The lack of yield response to N above 56 kg N /ha may be explained by the high N content of the soil profile (Table 1).

When averaged over N rates, fall/spring applied N was not significantly different from spring split N treatments, but when compared to fall applied N , fall/spring significantly increased protein and N in the tissue. Fall applied N, when compared to spring split N, significantly increased yield, N in the tissue and P uptake. Spring applied N, either in the spring split or fall /spring N treatments, significantly increased N in the tissue and protein when compared to fall applied N. Generally, N applied after the joint stage will generally increase protein and N in the tissue and have little or no effect on yield. The two last N splits were applied very close to heading and immediately after heading, thus, the amount of N available in the early crop growth stage was greater when N was fall applied compared to spring split N. Thus, N1 fall applied was about as effective as a N3 spring applied.

Yield and N and P uptake were significantly decreased with increasing P from 12.2 to 24.4 kg P /ha, although these results are strongly influenced by the unusually low yield for the N3P2 S2 treatments. When using LSD at .1 level to compare P levels for the same N rate, only at the N3 rate was P1 significantly different from P2. If the N3P2 S2 treatment is removed, the negative P effect disappears. There was a significant N x P interaction for yield.

Increasing SR, averaged over N2 and N3, significantly increased yield and N and P uptake and decreased protein and P in the grain. The decrease in protein with increasing SR is a result of a dilution effect, because of increased yield. The SR x N interaction was not significant.

Akron Irrigated 1985-1986

Climatic conditions for this location (Tables 4, 6) were similar to those at the dryland site. No diseases, weed infestations, damaging winds or storms occurred. No lodging was observed. Averaged over all the treatments, yield was 3.2 MT/ha, which is about 1 MT/ha below average for irrigated wheat in this region (Table 9). The yield reduction resulted from drought conditions from February to April and irrigation delay until May 15. Despite the early drought stress, increasing inputs increased production.

The first N increment (112 kg N /ha) significantly increased yield, protein, P in the tissue, and N and P uptake. In general, increasing N rates above N1 further increased tissue N, grain protein, and N uptake; however grain yield was decreased slightly. Similar results were obtained with the N effects averaged over seeding rate. Increases in grain P with increasing N rate were probably related to positive effects of N and P availability.

Fall applied N1 significantly increased tissue N, protein, P in the grain and N uptake compared to spring split applied N1. No differences in yield were detected, which is probably due to the early moisture stress.

Increasing P rates from 24.4 to 48.9 kg P /ha, averaged over N rates, significantly increased P in the tissue and P in the grain. There was a significant N x P interaction for N uptake. Increasing seeding rate, when averaged over N2 and N3, significantly increased yield and N and P uptake. For all the measurements, S1 was significantly different from S2 and S3, while S2 and S3 were only significantly different for yield and P in the grain. There was a significant N x SR interaction for N in the tissue and P uptake. Nitrogen uptake was only significant at $p = .12$ and yield at $p =.14$.

were only significantly different for yield and P in the grain. There was a significant N x SR interaction for N in the tissue and P uptake. Nitrogen uptake was only significant at p = .12 and yield at p =.14.

PGR application significantly decreased protein, but had no significant effect on the other measured parameters. There was a significant N x PGR interaction for P in the tissue.

Colby Irrigated 1986-1987

Climatic conditions at this location were similar to that described for the dryland site (Tables 4, 5). There was no weed infestation. No lodging was observed. Dry soil conditions at planting and immediately after resulted in uneven early growth, but all the plots were affected in the same way.

Averaged over all treatments, yield was 4.5 MT/ha, which is above average for irrigated wheat in this region. Comparing check vs all other treatments, all the measured parameters except yield responded positively and significantly to treatments (Table 10).

When averaged over P rates, no yield responses to N were observed. The lack of response to N may be due to the high content in N in the soil profile (Table 1). The with N fertilization.

When averaged over N rates, spring split N applications significantly improved yield, protein and N uptake compared to fall applied N. However, when comparing N1P1 S1 and N1P1F S1 treatments, only N uptake was significantly increased by spring split N compared to fall N. The improved response to spring split N is most likely related to increased available N during the vegetative period. Some of the fall N could have been partially leached prior to heading in late May. In addition, high N rates applied at planting may have induced some seedling kill, especially with the dry soil conditions in the fall. This explanation is further evidenced by the reduced yield observed with the fall N3 treatment compared to fall N2. Delaying the last two split N applications to GS 8 and GS 10 may have increased available N and improved N uptake relative to fall N.

Phosphorus fertilization did not significantly affect the measured parameters due to the high P content in the soil (Table 1). No significant N x P interaction was detected.

In general, seeding rate, when averaged over N2 and N3, had little effect in the measured parameters. Increasing seeding rate from S1 to S2 and S3 significantly increased N uptake, which was more related to increased tissue N content, although yields were increased with seeding rate but not significantly. The highest seeding rate also increased P in the tissue and to a lesser extent, P uptake over the S1 rate. However, comparing N1P1 S1 and N1P1 S2 treatments, S2 resulted in increased grain yield ($p = .10$) and N uptake ($p = .09$). There was no significant N x SR interaction.

There was no significant response to PGR application, because there was no lodging. There was a significant N x PGR interaction for P in the grain.

DISCUSSION

For the dryland sites, total rainfall during the growing season strongly influenced the results, increasing yield above average at the 1986-87 Colby site with above average rainfall and nearly average yields for the other two sites where average rainfall occurred. Compared to the check treatment, all the measured parameters were significantly increased by all treatments, except grain and tissue P concentration. This lack of response to P fertilization is a consequence of the high soil P content at each site. Generally, soils testing > 10 ppm Bray-1 P will not respond to P fertilization (7, 19, 29). The first N increment (56 kg N /ha) always significantly increased yield, grain protein and N and P uptake. Similar results have been well documented at other locations (7, 17, 19, 22, 29). No response to N fertilizer above 56 kg N /ha was observed. Increasing N from 56 kg N /ha (N1) to 168 kg N /ha (N3), only increased grain protein. Yield and N uptake were even decreased above the 112 kg N /ha rate at the 1986-87 Colby site, although no explanation is forwarded for this result. As a result of the early drought at the 1985-86 Colby site, no significant responses for all the measured parameters were observed above the first N increment, except for grain protein. Generally, if N is applied too late in the season, mainly after anthesis, grain protein is increased without affecting yield (7, 29). Thus, it is suggested that no N applications should be done after jointing, unless the N is specifically applied to increase grain protein. No consistent results were obtained with N application timing, which is similar to the results reported by (7) for several locations in Kansas, although it is common to increase protein when N is spring split applied. The total amount and distribution of the rainfall during the growing season are important factors that influence yield response to N timing. These data suggest that with a dry fall, no differences should be expected from N application timing, as observed at the 1985-86 Colby site. If during the early growing season the soil moisture is adequate, but is followed by a drought period, fall N application is likely to produce better yields than spring split N, as observed at the Akron location.

Seeding rate was the most important and consistent input affecting yield. Increasing seeding rates increased yield at all locations. These results confirm those from other studies (4, 19, 20, 22). Grain protein, due to the higher yields, may generally be decreased with increasing seeding rates (dilution effect), as reported by (29). Yields were not increased above $20.5 * 10^5$ seeds/ha (S2). Similarly to the results obtained by (21, 22, 32), plant growth regulator (CERONE) application will not affect yield if no lodging occurs.

In summary, it is suggested that N and seeding rates should not be increased above 56 kg N /ha and 20.5 * 10^5 seeds/ha, respectively. Fertilizer P should not be applied if soil available P is 10 ppm or above, and if no lodging is expected , as in most of the dryland wheat sites, no PGR (CERONE) should be applied. For N application timing , more research is suggested, due to the very inconsistent results from these experiments. However, spring split N should increase yield and grain protein if N is applied at the right time and the growing season has an average rainfall distribution.

For the irrigated sites, irrigation timing was a very important factor. If moisture stress occurs during the vegetative growth stage, grain yield may be decreased, which occurred at the Akron site. This may confirm the findings from (24), because the crop was stressed during reduction division in pollen mother cells and during part of the grainfill (16). Comparing check vs all other treatments, all the measured parameters were significantly increased with treatments at both locations, except yield at the Colby site and grain P at the Akron site. Dry conditions in the fall, delayed irrigation, and high profile N contributed to the lack of yield response. The first N increment (112 kg N /ha) increased grain P (Colby), N and P uptake (Colby and Akron), grain protein, yield and P in the tissue (Akron). Additional N increments (112 kg N /ha) had little or no effect on the measured parameters. The lack of response observed to N (Colby) and P (Colby and Akron) application is related to high N and P soil test levels. High levels of fertilizer close to the seed or seedlings, when the soil moisture is low, may induce seedling kill, and , as a result, poor stand and decreased yield as observed at the Colby site. Similar results were reported by (7, 19, 29). Nitrogen increased P uptake in the grain at both locations, and also tissue P at the Colby site. Generally, P uptake is increased in the presence of the N in the same soil zone (12). Under normal irrigation management, spring N splits increase yield, grain protein and N uptake compared to fall N, confirming the conclusions of (7, 19). However, if irrigation is delayed and stress occurs before anthesis, provided soil moisture is adequate at the beginning of the growing season, spring N split applications will not be as efficient as when N is fall applied because the crop will not be able to use the N that was applied in the spring due to water stress. In general, increasing seeding rate increased yield, and N and P uptake, as in the experiments from (4, 19, 20, 22). If no lodging occurs, PGR (CERONE) application will not uptake, as in the experiments from (4, 19, 20, 22). If no lodging occurs, PGR (CERONE) application will not affect yield, although at the Akron site grain protein was significantly decreased. The lack of yield response when no lodging occurs confirms the findings from (21, 22, 32).

It is recommended that N rates should not exceed 112 kg / ha, no P fertilizer should be applied to soil testing high in available P. Seeding rate should not be increased above $33.4 * 10^5$ seeds / ha. If no lodging is expected to occur, PGR - CERONE - should not be applied. Spring N split applications, as a complement to fall applied N, are suggested to increase yield and grain protein. Poor irrigation management at both locations influenced responses to inputs, thus results should be used with caution.

Table 1. Selected soil characteristics for the dryland and irrigated wheat sites.

	Texture	O.M[b]	pH[b]	NO_3-N[a]	$NaHCO_3$-P[b]
		g/kg		-- kg/ha	--
Dryland					
Colby 1985-86	SL	23	6.8	164	76
Colby 1986-87	SL	22	6.6	116	84
Akron 1985-86	SCL	12	6.8	128	56
Irrigated					
Colby 1986-87	SL	21	7.3	108	64
Akron 1985-86	SL	15	7.2	124	104

a) 0 to 1.5 m sample depth.
b) 0 to 30 cm sample depth.

Table 2. Treatment combinations and rates of nitrogen, phosphorus, and seed.

NITROGEN treat		NITROGEN rates DL	NITROGEN rates IRR	PHOSPHORUS treat	PHOSPHORUS rates DL	PHOSPHORUS rates IRR	N Timing	SEED treat	SEED rates DL	SEED rates IRR	PGR
		-- kg/ha -			-- kg/ha--				-seeds/ha x 10^5		
N0		-	-	P0	-	-	-	S2	20.5	33.4	...
N1		56	112	P1	12.2	24.4	F	S1	13.1	22.2	...
N1		56	112	P1	12.2	24.4	S	S1	13.1	22.2	...
N1		56	112	P2	24.4	48.9	S	S2	20.5	33.4	...
N1	xx	56	112	P2	24.4	48.9	S	S1	13.1	22.2	...
N1	xx	56	112	P2	24.4	48.9	F	S1	13.1	22.2	...
N2		112	224	P2	24.4	48.9	S	S1	13.1	22.2	...
N2		112	224	P2	24.4	48.9	S	S2	20.5	33.4	...
N2		112	224	P2	24.4	48.9	S	S3	27.8	44.5	...
N3		168	336	P2	24.4	48.9	S	S1	13.1	22.2	...
N3		168	336	P2	24.4	48.9	S	S2	20.5	33.4	...
N3		168	336	P2	24.4	48.9	S	S3	27.8	44.5	...
N1		56	112	P1	12.2	24.4	S	S2	20.5	33.4	...
N2		112	224	P1	12.2	24.4	S	S2	20.5	33.4	...
N3		168	336	P1	12.2	24.4	S	S2	20.5	33.4	...
N1	^	56	112	P2	24.4	48.9	S	S2	20.5	33.4	PGR
N2	&	112	224	P2	24.4	48.9	S	S2	20.5	33.4	PGR
N3	&	168	336	P2	24.4	48.9	S	S2	20.5	33.4	PGR
N1	^	56	112	P2	24.4	48.9	F	S2	20.5	33.4	...
N2	^	112	224	P2	24.4	48.9	F	S2	20.5	33.4	...
N3	^	168	336	P2	24.4	48.9	F	S2	20.5	33.4	...
N1	x	56	112	P2	24.4	48.9	F/S	S2	20.5	33.4	...
N2	x	112	224	P2	24.4	48.9	F/S	S2	20.5	33.4	...
N3	x	168	336	P2	24.4	48.9	F/S	S2	20.5	33.4	...

x only Colby Dryland 1986-87.
xx only Akron irrigated.
^ Colby irrigated and dryland 1986-87.
& not used at Colby dryland sites.
S fall applied N + 3 spring N splits at GS 6,8 and 10.
F all N fertilizer was fall applied.
F/S N applied in fall (50%) and spring (50%) at GS 6.

Table 3. Grain yield and protein and P concentration and tissue N and P concentration of dryland wheat grown with different N, P and seeding rate treatments at Colby, Kansas, during 1985-86.

Treatment		Yield	Protein	Tissue N	Tissue P	Grain P
		Mg/ha	g/kg			
CHECK S2		2.45	11.8	1.08	.13	.35
N1P1F S1		2.45	13.0	1.23	.13	.35
N1P1 S1		2.48	12.9	1.28	.15	.35
N1P1 S2		2.69	12.9	1.21	.13	.34
N1P2 S2		2.68	13.0	1.22	.13	.35
N2P1 S2		2.74	13.0	1.21	.13	.34
N2P2 S1		2.39	13.3	1.34	.16	.37
N2P2 S2		2.72	13.2	1.24	.13	.35
N2P2 S3		2.75	12.9	1.25	.13	.34
N3P1 S2		2.74	13.2	1.20	.12	.35
N3P2 S1		2.29	13.3	1.40	.15	.37
N3P2 S2		2.60	13.5	1.27	.13	.36
N3P2 S3		2.74	13.2	1.25	.13	.35
	Mean	2.59	13.0	1.24	.14	.35
	LSD .05	.16	.4	.09	.01	.02
	LSD .1	.13	.3	.07	.01	.01
	CV	4.4	1.9	5.0	7.6	3.2
	R-Square	.75	.79	.70	.59	.58

1 df Contrasts	Yield	Protein	Tissue N	Tissue P	Grain P
	p > F				
Check vs Others	.01	<.01	<.01	.32	.38
Check vs N1	<.01	<.01	<.01	.94	.86
Fall vs Spring	.68	.56	.35	.14	.93
P effect	.23	<.01	.19	.94	.32
N effect	.77	<.01	.51	.68	.17
N * P	.23	.16	.37	.41	.95
SR effect	<.01	.05	<.01	<.01	<.01
SR * N	.47	.10	.31	.83	.69
N1 vs N2 over P	.47	.22	.78	.83	.87
N1 vs N3 over P	.77	<.01	.51	.68	.17
N2 vs N3 over P	.31	.01	.70	.54	.22
S1 vs S2 over N2,N3	<.01	.25	<.01	<.01	<.01
S1 vs S3 over N2,N3	<.01	.05	<.01	<.01	<.01
S2 vs S3 over N2,N3	.15	<.01	.94	.76	.22

Table 4. Total Monthly Precipitation at Colby and Akron Branch Stations

Month	Colby				Akron			
	AVG[a)]	1985	1986	1987	AVG[b)]	1984	1985	1986
	--------- mm ---------				--------- mm -----------			
Jan	9	-	0	5	8	10	12	3
Feb	13	-	7	17	8	18	5	28
Mar	29	-	18	55	20	38	8	7
Apr	46	-	27	27	44	44	58	51
May	75	-	132	105	76	59	84	63
Jun	79	-	44	89	63	80	33	90
Jul	75	-	46	127	68	76	115	9
Aug	56	-	28	29	49	71	24	26
Sep	37	55	73	6	34	13	60	17
Oct	27	53	51	0	25	44	24	26
Nov	16	11	9	26	13	11	17	11
Dec	11	10	8	-	11	9	14	5
Total	473	-	443	486	419	473	454	336

a) AVG is a 70-year average for this location.
b) AVG is a 80-year average for this location.

Table 5. Average monthly air temperature at the Colby Branch Experiment Station.

MONTH	TEMPERATURE									
	Mean Month				Avg. Maximum			Avg. Minimum		
	AVG.	1985	1986	1987	1985	1986	1987	1985	1986	1987
Jan	-3	-	3	-1	-	12	6	-	-7	-9
Feb	0	-	1	2	-	9	9	-	-7	-4
Mar	3	-	7	2	-	17	9	-	-2	-5
Apr	9	-	11	10	-	20	18	-	-6	1
May	15	-	15	16	-	23	23	-	7	10
Jun	21	-	22	22	-	30	31	-	14	14
Jul	25	-	24	24	-	33	32	-	16	16
Aug	24	-	23	22	-	31	29	-	15	14
Sep	18	16	19	-	24	26	-	9	11	-
Oct	12	9	11	-	17	18	-	1	3	-
Nov	3	-1	3	-	4	11	-	-7	-6	-
Dec	-2	-10	-1	-	2	7	-	-10	-8	-

AVG. is a 70-years average for this location.

Table 6. Average monthly air temperature at the Akron Branch Station.

MONTH	TEMPERATURES									
	Mean				Maximum			Minimum		
	AVG	1984	1985	1986	1984	1985	1986	1984	1985	1986
Jan	-4	-5	-6	2	0	1	9	-12	-12	-6
Feb	-1	-1	-3	-1	4	4	7	-7	-11	-7
Mar	2	2	4	7	8	13	16	-4	-4	-1
Apr	8	4	10	9	11	18	17	-2	1	1
May	13	15	15	13	23	23	21	7	7	4
Jun	19	19	18	20	27	28	28	10	9	12
Jul	23	23	23	23	31	32	33	15	15	14
Aug	22	23	22	22	31	31	31	15	13	13
Sep	17	15	14	16	23	22	24	7	7	8
Oct	10	8	9	9	14	18	17	1	0	2
Nov	3	4	-2	3	12	4	10	-5	-8	-5
Dec	-2	-2	-5	-2	6	1	5	-9	-12	-9

AVG is a 77-year average for this location.

Table 7. Grain yield and protein and P concentration of dryland wheat grown with different N, P, seeding rate and plant growth regulator treatments at Akron, Colorado, during 1985-86.

Treatment	Yield	Protein	Grain P
	Mg/ha	---- g/kg ----	
N0P0 S2	1.67	11.6	.38
N1P1F S1	2.50	13.6	.40
N1P1 S1	2.36	12.6	.38
N1P1 S2	2.47	12.2	.37
N1P2 S2	2.29	12.8	.38
N1P2 S2 PGR	2.77	-	-
N2P1 S2	2.93	13.6	.39
N2P2 S1	2.25	14.1	.42
N2P2 S2	2.81	14.6	.39
N2P2 S2 PGR	2.73	-	-
N2P2 S3	2.86	14.2	.41
N3P1 S2	3.05	15.4	.41
N3P2 S1	2.21	15.3	.42
N3P2 S2	2.73	15.2	.41
N3P2 S2 PGR	2.75	-	-
N3P2 S3	2.64	14.8	.41
Mean	2.57	13.9	.40
LSD .05	.46	.80	.04
LSD .1	.38	.70	.03
CV	11.9	4.0	6.0
R-Square	.63	.87	.48

1 df Contrasts		p > F	
Check vs Others	<.01	<.01	.32
Check vs N1 over P	<.01	.02	.54
N1P1F S1 vs N1P1 S1	.53	.02	.09
PGR effect	.28	-	-
N * PGR	.17	-	-
P effect	.12	.04	.48
N effect	<.01	<.01	.01
N * P	.64	.13	.51
SR effect	<.01	.28	.28
SR * N	.54	.87	.87
N1 vs N2 over P	<.01	<.01	.12
N1 vs N3 over P	<.01	<.01	.01
N2 vs N3 over P	.85	<.01	.31
S1 vs S2 over N2,N3	<.01	.51	.22
S1 vs S3 over N2,N3	<.01	.55	.57
S2 vs S3 over N2,N3	.88	.23	.52

Table 8. Grain yield and protein and P concentration and tissue N and P concentration of dryland wheat grown with different N, P, and seeding rate treatments at Colby, Kansas, during 1986-87.

Treatment		Yield	Protein	Grain P	Tissue N	Tissue P
		Mg/ha	g/kg			
CHECK S2		3.55	12.2	.37	1.24	.17
N1P1F S1		3.51	12.2	.34	1.08	.15
N1P1 S1		3.93	12.4	.33	1.24	.17
N1P1 S2		4.42	12.5	.34	1.16	.15
N1P2F S2		4.73	11.9	.34	1.16	.17
N1P2F/SS2		4.66	12.4	.34	1.27	.17
N1P2 S2		4.30	12.2	.33	1.12	.14
N2P1 S2		4.54	12.6	.33	1.24	.15
N2P2F S2		4.47	12.2	.34	1.04	.14
N2P2F/SS2		4.29	12.7	.33	1.24	.15
N2P2 S1		3.19	12.9	.36	1.32	.15
N2P2 S2		4.45	12.6	.31	1.22	.15
N2P2 S3		4.58	12.5	.33	1.21	.15
N3P1 S2		4.43	13.0	.33	1.25	.15
N3P2F S2		4.55	12.2	.30	1.22	.15
N3P2F/SS2		4.02	13.0	.32	1.29	.15
N3P2 S1		3.29	13.1	.37	1.32	.16
N3P2 S2		3.75	13.0	.34	1.37	.17
N3P2 S3		4.38	13.0	.33	1.29	.15
	Mean	4.17	12.5	.33	1.22	.16
	LSD .05	.53	.5	.04	.15	.03
	LSD .1	.44	.4	.03	.13	.03
	CV	8.2	2.4	7.8	7.9	13.3
	R-Square	.75	.73	.46	.56	.35
1 df Contrasts		p > F				
Check vs Others		<.01	<.01	.08	.86	.23
Check vs N1		<.01	.15	.14	.16	.94
Fall vs Sp		<.01	<.01	.89	.04	.94
Fall vs Fall/Sp		.13	<.01	.88	.01	.87
Fall/Sp vs Sp		.25	.72	.98	.56	.21
N1P1FS1 vs N1P1S1		.08	.39	.48	.09	.54
N effect over P		.12	<.01	.90	<.01	.17
P effect		.03	.87	.86	.61	.80
P * N		.07	.13	.38	.12	.24
SR over N2,N3		<.01	.04	.01	.29	.78
N2 vs N3 over SR		.04	<.01	.08	.08	.86
SR * N		.45	.71	.89	.29	.80
S1 vs S2 over N2,N3		<.01	.13	<.01	.61	.66
S1 vs S3 over N2,N3		<.01	.04	.01	.29	.84
S2 vs S3 over N2,N3		.03	.48	.70	.56	.21
N1 vs N2 over P		.44	.14	.18	.08	.29
N1 vs N3 over P		.12	<.01	.90	<.01	.42
N2 vs N3 over P		.02	.02	.25	.15	.09

Table 9. Grain yield and protein and P concentration and tissue N and P concentration of irrigated wheat grown with different N, P, seeding rate and plant growth regulator treatments at Akron, Colorado, during 1985-86.

Treatment	Yield	Prot.	Tissue N	Tissue P	Grain P
	Mg/ha	g/kg	g/kg	g/kg	g/kg
CHECK S2	1.71	13.4	.93	.25	.47
N1P1F S1	3.17	16.7	1.02	.20	.54
N1P1 S1	3.23	14.2	.92	.22	.49
N1P1 S2	3.63	14.3	.89	.19	.47
N1P2F S1	2.88	16.2	1.07	.21	.50
N1P2 S1	2.97	14.1	.97	.21	.49
N1P2 S2	3.40	13.9	.96	.22	.48
N1P2 S2 PGR	3.36	13.6	.90	.20	.47
N2P1 S2	3.52	15.6	.95	.18	.47
N2P2 S1	3.09	16.0	1.03	.23	.49
N2P2 S2	3.32	16.3	1.12	.21	.50
N2P2 S2 PGR	3.38	15.8	1.07	.22	.48
N2P2 S3	3.42	15.7	1.10	.19	.47
N3P1 S2	3.26	16.9	1.15	.21	.49
N3P2 S1	2.97	16.5	1.23	.23	.49
N3P2 S2	3.28	17.2	1.11	.21	.51
N3P2 S2 PGR	3.31	16.1	1.20	.21	.50
N3P2 S3	3.65	16.3	1.03	.20	.49
Mean	3.19	15.5	1.04	.21	.49
LSD .05	.34	.9	.16	.03	.04
LSD .1	.29	.7	.13	.02	.03
CV	7.4	3.7	10.4	9.3	4.7
R-Square	.83	.88	.56	.54	.45
1 df Contrasts	p > F				
Check vs Others	<.01	<.01	.04	<.01	.19
Check vs N1	<.01	.09	.96	<.01	.87
Fall vs Sp over P	.56	<.01	.07	.29	.02
PGR effect	.88	.01	.90	.52	.12
N * PGR	.73	.13	.20	.09	.76
P effect	.16	.28	.16	.01	.10
N effect	.08	<.01	<.01	.89	.04
N * P	.44	.22	.49	.11	.73
SR over N2,N3	<.01	.49	.27	<.01	.36
N2 vs N3 over SR	.82	<.01	.42	.97	.26
SR * N	.14	.99	.02	.62	.48
N1 vs N2 over P	.47	<.01	.07	.23	.53
N1 vs N3 over P	.08	<.01	<.01	.89	.04
N2 vs N3 over P	.27	<.01	.12	.28	.10
S1 vs S2 over N2,N3	.03	.06	.84	.04	.28
S1 vs S3 over N2,N3	<.01	.49	.27	<.01	.36
S2 vs S3 over N2,N3	.05	<.01	.37	.13	.04

Table 10. Grain yield and protein and P concentration and tissue N and P concentration of irrigated wheat grown with different N, P, seeding rate and plant growth regulator treatments at Colby, Kansas, during 1986-87.

Treatment	Yield	Protein	Grain P	Tissue N	Tissue P
	Mg/ha	g/kg			
CHECK S2	4.44	11.3	.39	1.21	.19
N1P1F S1	4.01	12.7	.48	1.37	.21
N1P1 S1	4.45	13.2	.44	1.35	.22
N1P1 S2	4.97	12.9	.43	1.36	.20
N1P2F S2	4.30	12.5	.45	1.33	.21
N1P2 S2 PGR	4.44	13.3	.41	1.44	.22
N1P2 S2	4.48	13.4	.44	1.36	.20
N2P1 S2	4.50	13.4	.40	1.44	.21
N2P2F S2	4.78	12.7	.44	1.47	.22
N2P2 S1	4.27	13.5	.43	1.50	.21
N2P2 S2 PGR	4.66	13.6	.44	1.38	.19
N2P2 S2	4.58	13.4	.44	1.42	.20
N2P2 S3	4.85	13.6	.42	1.24	.18
N3P1 S2	4.79	13.6	.44	1.45	.22
N3P2F S2	3.56	12.9	.45	1.38	.20
N3P2 S1	4.53	13.7	.42	1.52	.22
N3P2 S2 PGR	4.78	13.9	.45	1.49	.23
N3P2 S2	4.86	13.5	.40	1.36	.21
N3P2 S3	4.45	13.8	.44	1.50	.20
Mean	4.54	13.2	.43	1.39	.21
LSD .05	.65	.8	.06	.23	.03
LSD .1	.54	.6	.05	.19	.02
CV	9.2	3.7	8.8	10.4	8.5
R-Square	.51	.74	.43	.34	.47
1 df Contrasts			p > F		
Check vs Others	.70	<.01	.05	<.01	.02
Check vs N1 over P	.26	<.01	.1	.09	.26
P effect	.13	.58	.86	.57	.34
Fall vs Spring	.02	<.01	.23	.81	.26
N1P1FS1 vs N1P1S1	.16	.35	.18	.92	.80
PGR effect	.86	.50	.41	.40	.11
N * PGR	.93	.33	.09	.74	.66
N over P	.90	.06	.41	.55	.11
SR over N	.94	.78	.15	.75	.12
N1P1S1 vs N1P1S2	.10	.57	.84	.98	.16
P * N	.22	.23	.32	.58	.52
N * SR	.14	.44	.45	.18	.86
N1 vs N2 over P	.77	.28	.47	.38	.76
N1 vs N3 over P	.90	.06	.41	.55	.11
N2 vs N3 over P	.89	.36	.87	.84	.19
N2 vs N3 over SR	.95	.52	.50	.21	.10
S1 vs S2 over N2,N3	.16	.67	.97	.13	.15
S1 vs S3 over N2,N3	.27	.57	.57	.08	<.01
S2 vs S3 over N2,N3	.74	.29	.52	.78	.12

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DRYLAND AND IRRIGATED HARD RED WINTER WHEAT

(*TRITICUM AESTIVUM* L.) MANAGEMENT

IN THE CENTRAL GREAT PLAINS

by

JOSE PEDRO TAVARES

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ABSTRACT

Wheat (*Triticum aestivum* L.) yields have increased with intensive management systems in humid regions, but few studies have been conducted in the central Great Plains environment. Dryland and irrigated hard red winter wheat experiments were conducted between 1985 and 1987 at several locations in both Colorado and Kansas to evaluate the effect of various management factors on grain yield, protein, and N and P content and uptake in the grain, and tissue N and P with changes in management levels. The management factors studied were seeding rate, N and P rates, N application timing, and plant growth regulation. Similar treatments were used for both dryland and irrigated studies, except that fertilizer and seeding rates were greater for the irrigated sites. Treatments were arranged in a randomized complete block design with four replications. The studies were done on a Rago loam (fine, montmorillonitic, mesic, Pachic Argiustoll), a Haxton silt loam (fine-loamy, mixed, mesic, Pachic Argiustoll), and a Keith silt loam (fine-silty, mixed, mesic Aridic Argiustoll) soils. Results for the dryland sites were strongly influenced by growing season rainfall. Seeding rate was the most important factor for increasing yield and N and P uptake in both dryland and irrigated experiments. Although soil profile N was high at all

locations, increases in yield and protein were observed with the first N increment. In general, spring split and fall applied N produced similar results. With a dry fall, no differences should be expected from N application timing, while if the drought occurs in spring after a period of adequate moisture, fall N application is likely to produce better yields than spring split N. For dryland wheat, it is suggested that N rates not exceed 56 kg N /ha and seeding rate should not be above $20.5 * 10^5$ seeds /ha. For irrigated wheat, N rates should not exceed 112 kg N /ha and seeding rate should be $33.4 * 10^5$ seeds /ha. Due to the high soil P content, no response was observed to P fertilization. No lodging was observed, and PGR application did not affect the measured parameters. For both dryland and irrigated wheat, no P fertilizer should be applied to soil testing high in available P. No PGR should be applied if lodging is not expected to occur. In general, improved management increased yields when compared to the common practices used in the region.